EXPOSURES OF WATER ICE IN THE NORTHERN MID-LATITUDES OF MARS.

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Introduction: Water ice is exposed in the martian north polar cap [1], and is occasionally exposed beyond the cap boundary. Orbital gamma ray spectrometry data strongly imply the presence of water ice within meters of the surface at latitudes north of approximately 60° [2]. We have examined mid-latitude areas of the northern plains displaying evidence of residual ice-rich layers, and report possible present-day exposures of ice. These exposures, if confirmed, could constrain the latitudinal and temporal stability of surface ice on Mars.

Ice-Rich Layer: Polygonal features with dimensions of approximately 100 m, bounded by cracks, are commonly observed on the martian northern plains. These features are generally attributed to thermal cracking of ice-rich sediments, in direct analogy to polygons in terrestrial polar regions [3,4]. We mapped polygons in the northern mid-latitudes (30° to 65° N) using all Mars Orbiter Camera (MOC) narrow-angle images (resolution ~ 5 m / pixel) from 9/97 through 9/03 [5]. While MOC images show that polygons are scattered across the northern plains, 74% of such images are centered in western Utopia Planitia (40° to 50° N; 258° to 288° W; Fig. 1).

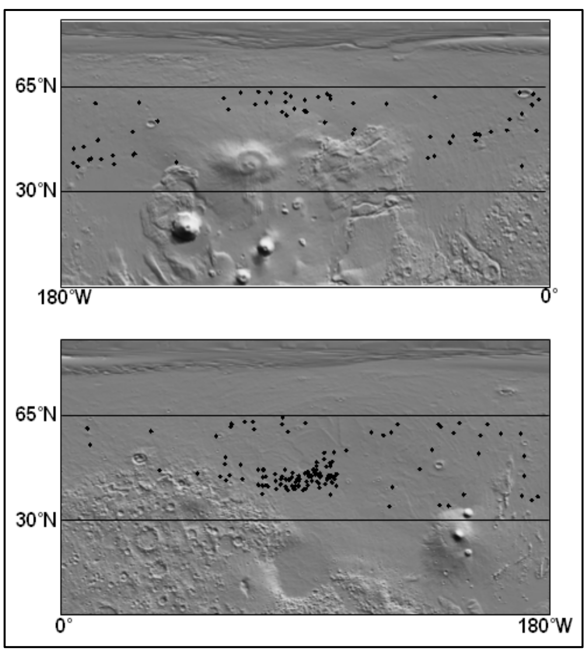

Figure 1. MOC images showing polygons – latitude range 30° to 65 ° N

This region largely overlaps the Late Amazonian Astapus Colles unit, characterized by polygonal terrain and nested pits "consistent with periglacial and thermokarst origins" [6]. Other authors suggest that this morphology reflects the presence of a generally continuous ice-rich mantle [3,4]. Ice stability models [7], orbital spectrometry [2], and the occurrence of thermokarst morphologies [5] indicate that the ice is concentrated below 1 m and is currently subliming.

In a follow-on study McBride et al. [8] measured all of the impact craters, with diameters between 100 m and 4 km, occurring on polygonal terrain between 30° and 65° N. The size-frequency distribution of the craters larger than 1 km is concordant with the distribution for larger craters (> 8 km) in western Utopia (N. Barlow, *personal communication*), indicating preservation of a late Hesperian crater population. Of the craters on polygonal terrain, 97% predate the polygonal cracks, indicating Amazonian-age deposition or activation of an ice-rich layer. The crater size-frequency distribution on polygonal terrain shows a marked deficiency of craters smaller than 1 km, suggestive of mantling. A subset of such craters with diameters between 460 m and 1.12 km are buried to their rims by polygonal terrain, indicating that the ice-rich layer is locally 30 to 40 m thick [8]. These findings are in accord with models of obliquity-driven deposition and sublimation of ice-rich mantles in the northern mid-latitudes of Mars [9]. One recent model of the climate during high obliquity epochs specifically predicts ice accumulation in western Utopia [10].

Bright and Dark Polygonal Cracks: Many polygons, particularly in the northern portion of the study area, are bounded by cracks significantly brighter than the polygon centers. Other polygons, particularly farther south, are bounded by dark cracks (Figs. 2,3).

A survey of the longitude range 240° to 300° W showed that polygons at latitudes between 60° and 65° N are generally demarcated by bright cracks. Dark cracks bound polygons at latitudes of 35° to 60° N [5].

A more extensive examination of all MOC images (1997 through 2003) covering 30° to 65° N supported these initial results. At latitudes of 55° to 65° N, 45 MOC images show polygons – with 73% showing bright cracks. Between 40° and 55° N, 141 images show polygons – with 66% showing dark cracks [11]. The farthest north polygon bounded by dark cracks

lies at 54° N; the farthest south polygon bounded by bright cracks lies at 50° N.

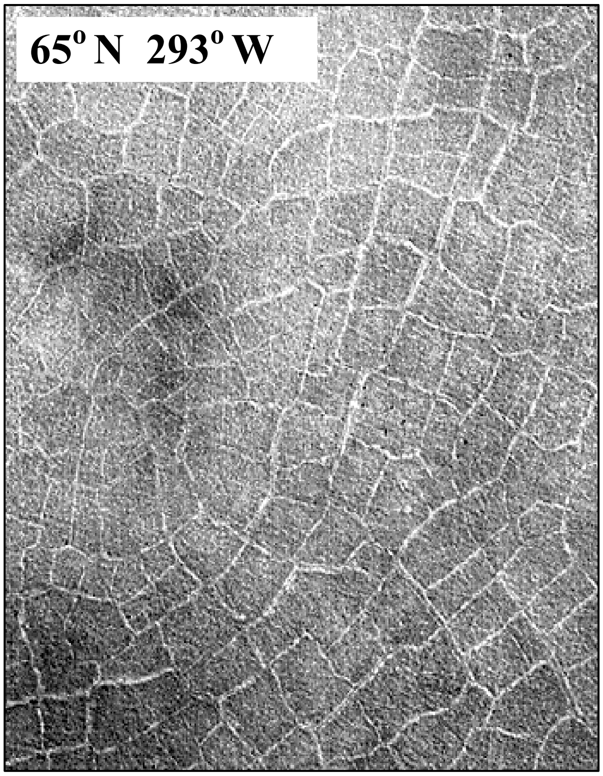

Figure 2. Bright polygonal cracks (MOC E0300299)

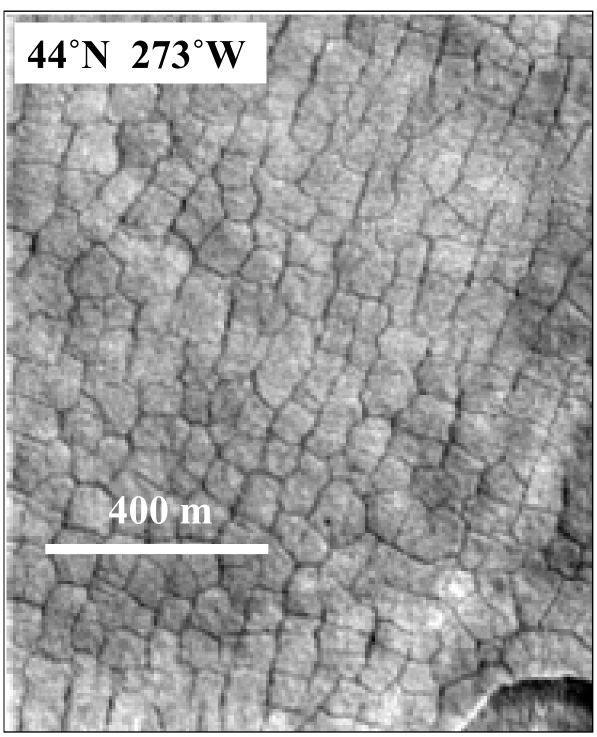

Figure 3. Dark polygonal cracks (MOC M0401631)

Bright and Dark Spots: Many of the highest resolution MOC frames showing polygons in the northern plains also show small numbers of bright and dark spots scattered across the terrain (Figs. 4,5). The spots are particularly noticeable in western Utopia Planitia, the area with the highest concentration of polygons.

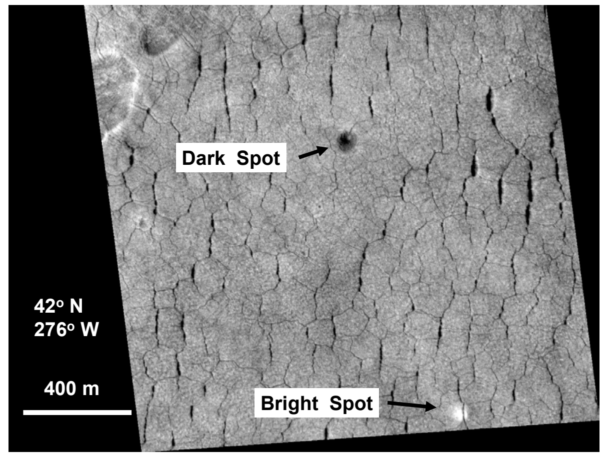

Figure 4. Dark and bright spots on polygons (MOC S03001)

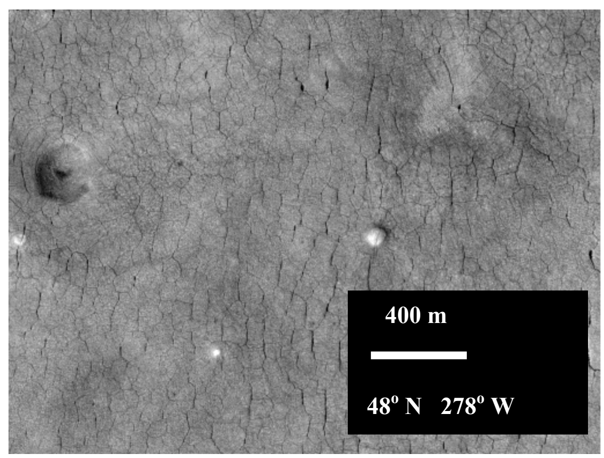

Figure 5. Bright spots on polygons (MOC E0401564)

The spots range from tens of meters to approximately 100 meters in diameter. Many of the bright spots are centered on cracks bounding the polygons. Some, but not all, of the dark spots are also centered on cracks. The spots are uniformly bright or dark at MOC resolution. Neither type shows evidence of raised rims nor ejecta blankets. The spot morphologies are distinctly simpler than those of the freshest small impact craters imaged by MOC [12; Fig. 6].

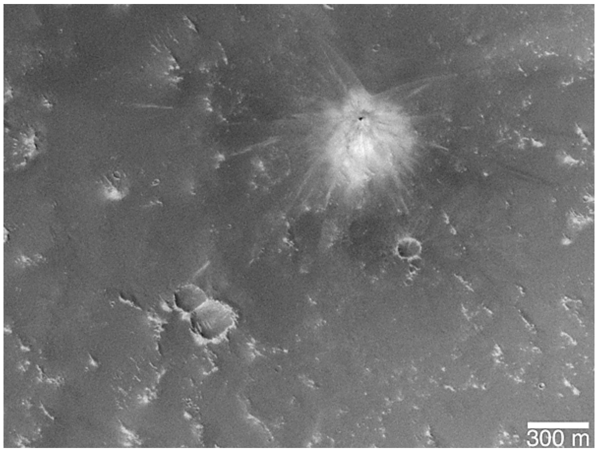

Figure 6. Recent (2002 or 2003) 23-m diameter impact crater in Arabia Terra (MOC S1502724)

Discussion – Bright and Dark Polygonal Cracks: Sublimation polygons have been formed and preserved in the upper reaches of the Antarctic Dry Valleys [13]. These polygons form under strongly sub-freezing conditions, without involvement of liquid water. Exposed ice and snow may be preserved in these features, particularly in the bounding cracks (Fig. 7).

Figure 7. Polygons in old glacial till deposits from McKelvey Valley, Antarctica; snow preferentially preserved in the cracks; polygons ~ 10 m across (photograph by David Sudgen)

Commonly in Antarctica exposed ice is removed by sublimation, owing to the low humidity and katabatic winds. The polygon morphology is characteristically preserved even when no ice is visible at the surface. Ice remains at the cores of these polygons, where the ice is shielded from sublimation by overlying sediments [13].

The martian polygons formed at latitudes of 55^o to 65^o N characteristically have bright bounding cracks, which we interpret as exposed water ice. Thermal models and orbital spectrometry both indicate that the stability line for near-surface water ice is currently at latitudes north of 60^o.

The majority of polygons in our survey located between 40^o and 55^o N show dark bounding cracks. These are interpreted as polygons from which the exposed ice has been removed by sublimation. This interpretation indicates that the long-term stability limit for exposed ice, even in deep cracks, lies near 55^o N.

Alternatively, the polygonal cracks may be bright due to concentrations of bright minerals, including salts. These salts could be initially frozen into the ice, and preserved in the polygonal bounding cracks when the ice sublimes.

Discussion – Bright and Dark Spots: The bright spots are also interpreted as exposed ice, due to their prevalence on terrain mapped as ice rich. The dark spots are interpreted as former bright spots, which have darkened as the exposed ice is lost by sublimation. If the bright spots are indeed composed of water ice this is a reasonable interpretation, since these spots are prevalent at latitudes around 40^o – 50^o N, well south of the ice stability line. This interpretation implies that the bright spots are unstable and may be short-lived.

The bright spots may be formed by any of several mechanisms. One possible origin is by small meteorite impacts. Analogous bright craters dot the surfaces of the icy satellites of Jupiter, where impacts excavate ice-rich material from beneath dark surfaces [14]. If the spots are formed in this way, they represent a population of craters considerably smaller than the 23-m diameter crater shown in Fig. 6.

Another possibility is that ice rose to the surface along bounding cracks. Such "ice diapirs" have been proposed for features on Mars, Europa, and Enceladus [15,16,17].

Several authors [18,19,20] have recently suggested that the bright spots may be the martian equivalents of pingos, ice-cored mounds found in periglacial regions on Earth. Pingos in Canada's Mackenzie river delta are characteristically 10's to 100's of meters in diameter, roughly the scale of the martian features. Terrestrial pingos from which the ice core has melted often collapse to form depressions similar to the martian dark spots.

Finally, the martian bright spots may be composed of bright salts, remaining from the sublimation of ices or brines. Salt deposits might be stable over considerably longer periods than exposed ice.

Future Observations: The ground-penetrating radars currently in orbit on Mars Express and the Mars

Reconnaissance Orbiter (MRO) should be able to confirm the presence and measure the depth of the interpreted ice-rich layer that forms the Astapus Colles unit. If this layer is confirmed it will strengthen the interpretation of bright polygon bounding cracks and bright spots as exposed ice.

HiRISE images of the northern plains are showing unprecedented details of the polygonal cracks. These images also have the potential to reveal ejecta morphologies around the small bright spots. Future HiRISE images that include bright spots, compared to MOC images taken years earlier, will illustrate the temporal stability of the spots.

The MRO CRISM spectrometer, with multiple spectral bands and a spatial resolution around 20 m, should allow mineralogical identification of the material exposed in the polygonal bounding cracks and in the bright spots. These data may conclusively demonstrate whether these features are composed of ice, salt, or a mixture of both.

The Phoenix lander – scheduled for launch in August, 2007 – will likely be targeted to a region of small (~ 10 m diameter) polygons, bordered by bright cracks, in the northern plains. This lander could collect samples of material in these cracks and provide detailed chemical analyses.

Implications: If the bright material in cracks and spots is indeed exposed ice, its presence in the martian mid-latitudes will serve as an additional test of ice stability models and the sensitivity of orbital spectrometry. The bright spots can provide an indication of near-surface ice independent of polygonal and thermokarst terrain. Recent ice diapirs or pingos, if confirmed, will provide further demonstrations that Mars is an active planet with a complex water cycle. Alternatively, if the bright features prove to be salts, their analyses will provide key geochemical data concerning the recent martian cyrosphere.

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